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Aortic Remodeling Following Sun's Procedure for Acute Type A Aortic Dissection

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: Sun's procedure is a surgical technique widely used in type A aortic dissection. The purpose of this study was to analyze clinical outcomes and morphologic changes in true and false lumen by computed tomography (CT) angiography after Sun's procedure.

Material/Methods: We retrospectively reviewed 51 patients who underwent Sun's procedure for acute Stanford type A aortic dissection extending down to iliac bifurcation between January 2013 and December 2014. The images of preoperative, one-month, three-month, and six-month follow-up were analyzed by CT angiography to measure the area and diameter of true and false lumen.

Results: Four patients died before surgical intervention and postoperative deaths occurred in five patients (in-hospital mortality rate 10.6%). Only 42 patients (36 male, 6 female; mean age, 45.9±9.8 years; range, 24–65 years) with acute type A aortic dissection were involved in our study. Thirty-five patients (83.3%) suffered from chest or abdominal pain and only one patient (2.4%) was asymptomatic. Thirty-seven patients (88.1%) had hypertension as the most common comorbidity. In the ascending aorta, false lumen was eliminated and the change of true lumen was not significant ($p>0.05$). In the descending aorta, complete and partial thrombosis of false lumen were observed in eight patients (19.0%) and 33 patients (78.6%) by one-month follow-up CT scan, respectively. After the six-month follow-up, the rate of complete thrombosis increased to 36.1% and partial thrombosis decreased to 61.9%. The area and maximal diameter of true lumen were increased significantly ($p<0.05$), whereas significant decreases were found in the area and maximal diameter of false lumen ($p<0.05$). In the abdominal aorta, thrombosis was found in 52.4% patients at one-month follow-up CT. Furthermore, there were no significant changes in both true and false lumen within three months ($p>0.05$). Nevertheless, the false luminal area and maximal diameter decreased significantly ($p<0.05$) after six months, while these changes of true lumen were not significant ($p>0.05$).

Conclusions: After Sun's procedure, aortic remodeling was a continuous process and occurred in a predictable model, and the extent of aortic remodeling varied at different levels. Remodeling in descending thoracic aorta was earlier than it was in abdominal aorta.

MeSH Keywords: **Aortic Diseases • Cardiovascular Diseases • Surgery Department, Hospital**

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Background

Aortic dissection remains a relatively rare but catastrophic vascular disease. It is an event of sudden onset in which high blood flow and pressure make the aortic media split into double channels. The media extends forward and backward along the longitudinal axis of the aorta. Patients without treatment would die at a rate of 1% to 2% per hour on the first day and almost 50% patients present clinical symptoms within 48 hours, symptoms such as rupture, pericardial tamponade, valvular malfunction, or stroke [1,2]. Therefore, once diagnosed, all patients should be treated as soon as possible.

The optimal treatment of aortic dissections is still a formidable challenge for cardiovascular surgeons. The operation for type A dissection aims to prevent early death from rupture or malperfusion, to repair the intimal tears, to reconstruct a new blood passageway to increase tissue perfusion, and to prompt aorta remodeling. However, the mortality rate of conventional surgery for aortic dissection ranges from 10% to 27% [3]. Open surgery has been considered to be the mainstay in the management of patients with acceptable results [4–6], especially when type A dissection involves the aortic valve, coronary ostia, arch vessels, descending aorta, and abdominal aorta. Sun's procedure is a surgical approach proposed by Dr. LZ Sun and his team, which refers to total replacement of the aortic arch using a four-branched vascular graft combined with stented elephant trunk implantation in the descending aorta [7–9]. Sun's procedure provides a clearer operative field and simplifies the surgery with easier exposure. Over 1,000 cases of Sun's procedure indicated the rate of overall in-hospital mortality was 6.27% and an incidence of second-stage intervention was 4%. These percentages were higher in patients with other surgical approaches [7].

Aortic remodeling could be promoted by traditional open surgery combined with thoracic endovascular aortic repair (TEVAR). Many previous studies have demonstrated that successful TEVAR is beneficial to aortic remodeling in type B aortic dissection [10–12], but little has been reported about aortic remodeling after surgery in type A dissection [13], especially when dissections extend from the ascending into the descending aorta. This retrospective study aims to report our experience of management of acute type A aortic dissection using Sun's procedure and to assess the clinical outcome and aortic remodeling.

Material and Methods

Patient data

Patients with acute Stanford type A aortic dissection extending down to iliac bifurcation underwent Sun's procedure in the Department of Cardiovascular Surgery of the Second Xiangya Hospital of Central South University between January 2013 and December 2014. Dissection was confined to ascending and descending aorta in this study according to preoperative computer topography (CT) scans. This study was approved by the local Ethics Committee of the Second Xiangya Hospital. Informed consent was obtained from all patients or their relatives.

Surgical techniques

The surgical technique has been previously described [9,14]. All patients underwent a standard median sternotomy and total cardiopulmonary bypass (CPB). CPB was established via arterial cannulation of either the axillary artery (88% of the time) or the femoral artery (11.9% of the time). Venous cannulation was performed through the right atrium in all patients along with placement of a left ventricular vent via the right upper superior pulmonary vein. Cardiac arrest was achieved by antegrade perfusion of cold-blood cardioplegic solution into the coronary ostia. Selective cerebral perfusion (SCP) was established at a rate of 5–10 mL/kg/minute. Deep hypothermia and SCP were performed to protect brain function when nasopharyngeal temperature reached 18°C to 22°C. The ascending aorta and aortic arch were longitudinal opened. The intimal tear site was thoroughly inspected and then resected whenever possible. Aortic root procedures were performed according to the pathology of patients. The ascending aorta and arch were reconstructed by a four-branched prosthetic graft (Boston Scientific Inc., Boston, MA, USA). Stented elephant trunk (MicroPort Endovascular (Shanghai) Co., Ltd.) was implanted into the true lumen of proximal descending aorta, and then it was over sewn with the four-branch prosthetic graft in an end-to-end style. Left common carotid artery, brachiocephalic trunk, and left subclavian artery were anastomosed to the respective limbs of four-branch graft in turn.

Follow-up CTA imaging

Electrocardiogram (ECG)-triggered CT angiography (CTA) was routinely performed with a 64-slice multidetector row scanner (SenSation, Siemens, Germany). The images were scanned at 2-mm intervals from skull to femur, while enhanced images were obtained at 5–8 seconds after a bolus injection of nonionic contrast material. The diastolic phase of the cardiac cycle is chosen for image acquisition. All patients underwent CTA scans preoperative. Post-procedure CTs were obtained at one, three, and six months using the same imaging protocol. The aortic luminal area and diameter (both true and false lumen) were quantified by CT scan at nine levels of aortic location, including sinotubular junction (a1 and a2), bifurcation of pulmonary artery (b1 and b2), aortic arch (c), diaphragm (d), celiac trunk axis (e), left renal artery (f), and iliac bifurcation (g), as shown in Figures 1 and 2. The nine levels were grouped

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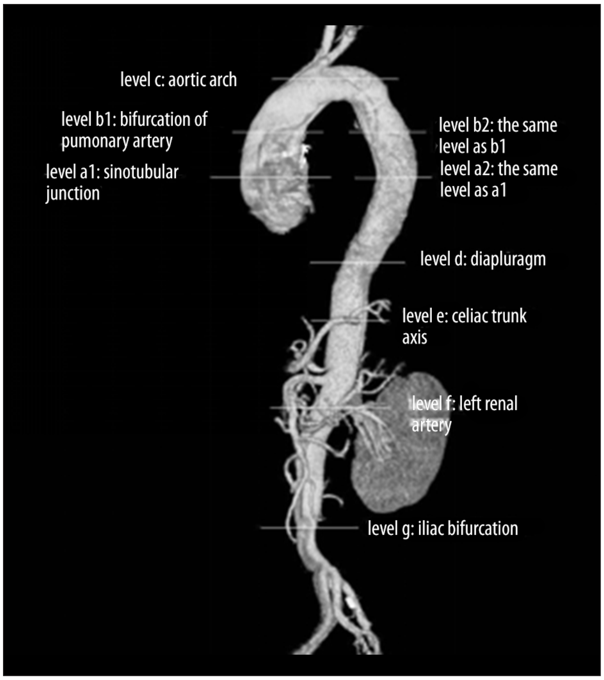

Figure 1. Aortic measurement at different levels.

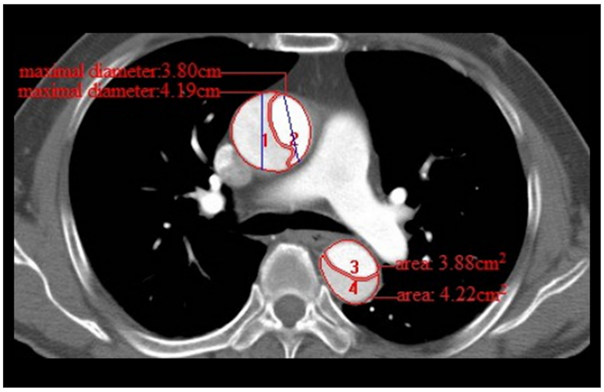

Figure 2. Area and diameter measurement of the true and false lumen. Number 1 and Number 3 were the maximal diameter and area of the false lumen, respectively. Number 2 and Number 4 were the maximal diameter and area of the true lumen, respectively.

into three segments: L1: ascending thoracic and arch (a1, b1, and c); L2: descending thoracic (a2, b2, and d); L3: abdominal (e, f, and g). The follow-up data were acquired in all patients.

Statistical analysis

Statistical analysis was performed using SPSS software (version 17.0; SPSS, Inc., Chicago, IL, USA). Continuous variables were presented as mean ± standard deviations, and paired *t*-test and repeated measures ANOVA were used in the analysis of variance. Categorical variables were expressed as frequencies with percentages and analyzed using the χ^2 test and Fisher's exact test. A value of $p<0.05$ was considered statistically significant.

Table 1. Demographics and clinical profiles of patients with acute type A aortic dissection.

Variable	Value (%)
Demographics	
Age (years)	45.9±9.8
Male	36 (85.7)
Female	6 (14.3)
Comorbidities	
Hypertension	37 (88.1)
Active smoker	23 (54.7)
Chronic obstructive pulmonary disease	6 (14.3)
Diabetes mellitus	4 (9.5)
Coronary heart disease	2 (4.8)
Marfan syndrome	8 (19.0)
Bicuspid aortic valves	3 (7.1)
Lower extremity ischemia	3 (7.1)
Previous cardiovascular operation	1 (2.4)
Clinical presentation	
Chest pain	28 (66.7)
Abdominal pain	7 (16.7)
Back pain	3 (7.1)
Asymptomatic	1 (2.4)

Results

Patient demographics and clinical profiles were presented in Table 1. Eleven patients with type A aortic dissection were not involved because they did not have extension down to the iliac bifurcation: they only had extension to the ascending aorta in four patients, the aortic arch in two patients, the celiac axis in three patients, and the left renal artery in two patients. Although 51 patients with acute type A aortic dissection was referred to this study, four patients died before surgical intervention due to aortic rupture. Postoperative deaths occurred in five patients (in-hospital surgical mortality 10.6%) due to multiple organ failure (n=2), gastrointestinal hemorrhage (n=2), and sepsis (n=1). Thus, only 42 patients (36 male and 6 female) with acute type A aortic dissection were involved in

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Table 2. Origination of visceral arteries.

Visceral artery	False lumen (%)	True lumen (%)	Both (%)
Celiac artery	4 (9.5)	29 (69.0)	9 (21.5)
Superior mesenteric artery	0 (0)	32 (76.2)	10 (23.8)
Right renal artery	9 (21.5)	30 (71.4)	3 (7.1)
Left renal artery	15 (35.7)	22 (52.4)	5 (11.9)

Table 3. Cardiopulmonary bypass data.

Variable	Value (%)
Axillary artery-right atrial bypass	37 (88.1)
Femoral- right atrial bypass	5 (11.9)
Cardiopulmonary bypass time (minutes)	257.1±80.8
Cross-clamp time (minutes)	125±50.1
Elective cerebral perfusion time (minutes)	41.7±22.6

Table 4. Surgical technique in aortic root.

Surgical procedure	Value (%)
Bentall procedure	12 (28.6)
Wheat procedure	1 (2.4)
Aortic valvuloplasty	3 (7.1)
Sinus of Valsalva reconstruction	15 (35.7)
Coronary artery bypass graft	3 (7.1)

our study. The average age was 45.9±9.8 years (range, 24–65 years). At the time of presentation, 35 patients (83.3%) suffered from chest or abdominal pain and only one patient (2.4%) was asymptomatic. Thirty-seven patients (88.1%) had hypertension as the most common comorbidity. More than a half of the patients were active smokers, and eight patients met the diagnostic criteria for Marfan syndrome. Bicuspid aortic valves were found in three patients, and one patient underwent cardiovascular surgery before. Table 2 shows the origination of visceral arteries.

All patients received total arch reconstruction combined with stented elephant trunk implantation under CPB with SCP. The median CPB time was 257.1 minutes (range: 117 to 485 minutes), and the median aortic cross-clamp time was 125.1 minutes (range: 57 to 280 minutes). The median SCP time was 41.7 minutes (range: 14 to 97 minutes). CPB data are shown in Table 3. Concomitant aortic root procedures included Bentall technique in 12 cases, Sinus of Valsalva reconstruction in 15

Table 5. Primary intimal tear site.

Variable	Value (%)
Ascending aorta	17 (40.5)
Transverse arch	14 (33.2)
Proximal descending aorta	9 (21.5)
Multiple	2 (4.8)

cases, aortic valvuloplasty in three cases, Wheat procedure in one case, and coronary artery bypass graft in three cases (Table 4). The primary intimal tear was located at ascending aorta in 17 patients, transverse arch in 14 patients, proximal descending aorta in nine patients, and multiple sites in two patients (Table 5). All the intimal tears were completely resected.

Follow-up CTA analysis

In L1 segments, because the ascending aorta and arch were replaced by artificial vessel, the false lumen was eliminated. The diameter and area of true lumen decreased slightly, but the mean differences of diameter and area decrease were not significant ($p>0.05$) during follow-up (Figures 3, 4).

In L2 segments, total and partial thrombosis of the false lumen were observed in eight patients (19.0%) and 33 patients (78.6%) in the initial postoperative CT scan, respectively. After six-month follow-up, the rate of total thrombosis nearly doubled (36.1%) and partial thrombosis decreased to 61.9%. The area and maximal diameter of true lumen were increased and then remained stable. The mean differences of area and maximal diameter increase were statistically significant ($p<0.05$) between the pre-procedural and post-procedural measurements. Conversely, the false lumen decreased significantly ($p<0.05$) (Figures 3, 4). Only one patient had patent false lumen, and the diameter of patent false lumen increased from 2.65 cm preoperative to 3.3 9 cm after 6-month surgery, while the area increased from 3.79 cm^2 to 5.37 cm^2.

In L3 segments, thrombosis was found in 52.4% patients in the first postoperative CT, and no significant changes were found in both true and false lumen within three months. Although

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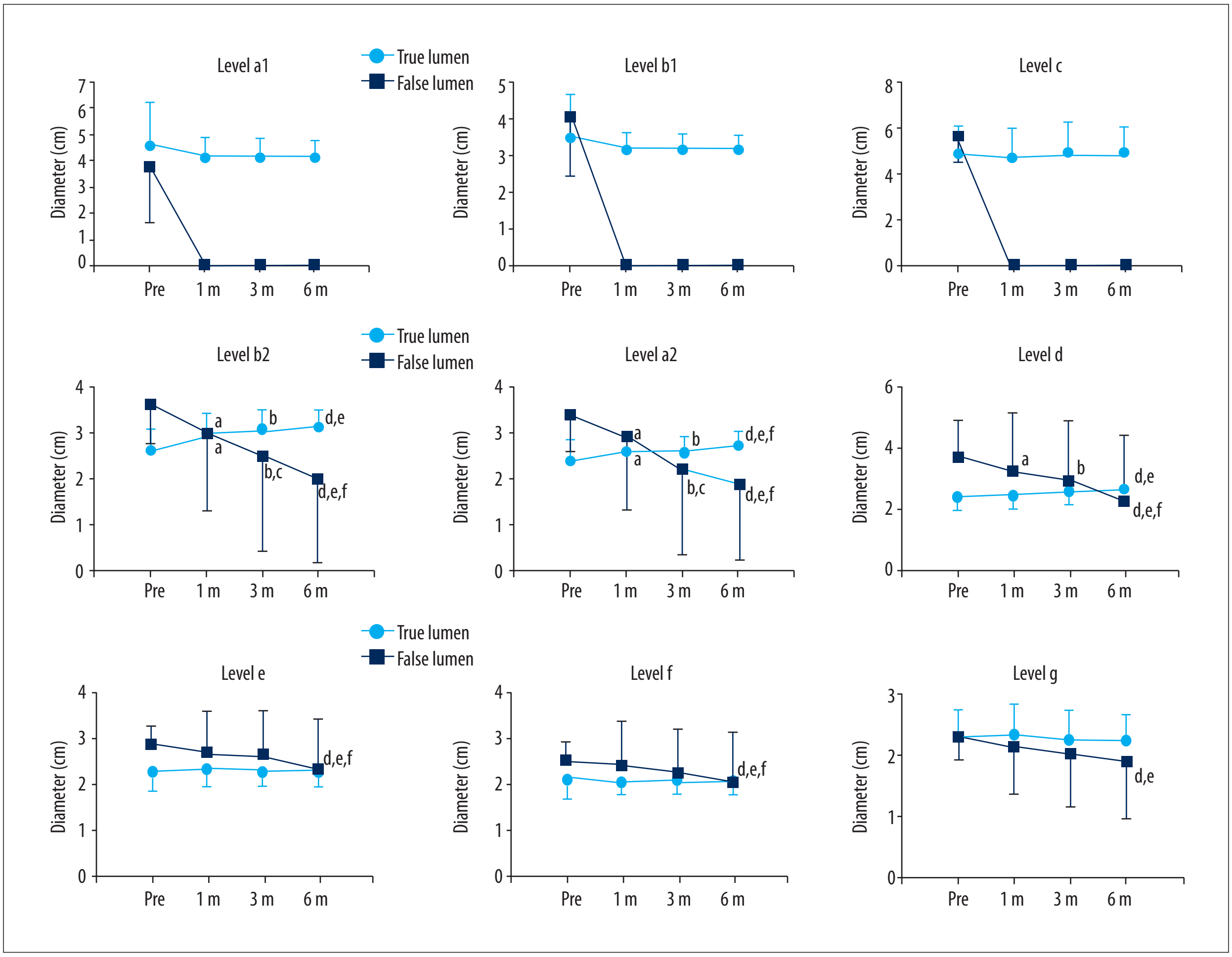

Figure 3. Changes in maximal diameter of true and false lumen at different levels after Sun's procedure. Diameter values were expressed as mean ±SD. Letters (a, b, c, d, e, and f) represent statistically significant (p<0.05). Different letters represent different p values in certain level. Level a: preoperative *vs.* 1-month; level b: preoperative *vs.* 3-month; level c: 1-month *vs.* 3-month; level d: preoperative *vs.* 6-month; level e: 1-month *vs.* 6-month; level f: 3-month *vs.* 6-month.

the false lumen area and maximal diameter decreased significantly after six months, the change of true lumen was not significant (Figures 3, 4). At one-month follow-up, the regression of patent false lumen occurred in 12 of 20 patients (60%), but expansion in 8 of 20 patients (40%). Thrombosis was not found in patients without thrombosis in L2 segments, which indicated that thrombosis formed in L3 segments was correlated with that in L2 segments.

Discussion

Although the early surgical outcomes of acute dissection are promising, the long-term outcomes remain great challenge. The reported overall survival rate of patients with dissection ranges from 50% to 80% in five years and from 30% to 60% in 10 years [15], which is to say, in many cases, patients who survive after the surgery are still confronted with aortic problems for a long time.

Aortic remodeling after surgery is a continuous process. The shrinkage or complete thrombosis of false lumen and expansion of true lumen are considered to be favorable postoperative anatomical changes of aortic dissection, while the patent and highly perfused false lumen is thought to be the cause of aortic enlargement and aneurysm resulting in reoperation or rupture [10,13,16]. Rodriguez et al. found 65.1% of patients developed complete thrombosis during follow-up. Moreover, the rates of patients who required a second intervention were different between positive and negative remodeling [17]. Cinrad et al. observed that the average maximum true lumen diameter increased significantly from 23.7 mm postoperative to 31.1 mm after one year. Concomitantly, the average maximum false lumen diameter decreased dramatically from 19.5 mm to 9.6 mm, and the positive remodeling was obviously effective to prevent late aneurysm formation [18]. These reports indicated that aortic remodeling could resolve the false lumen to prevent fatal aortic problems and therefore improved survival

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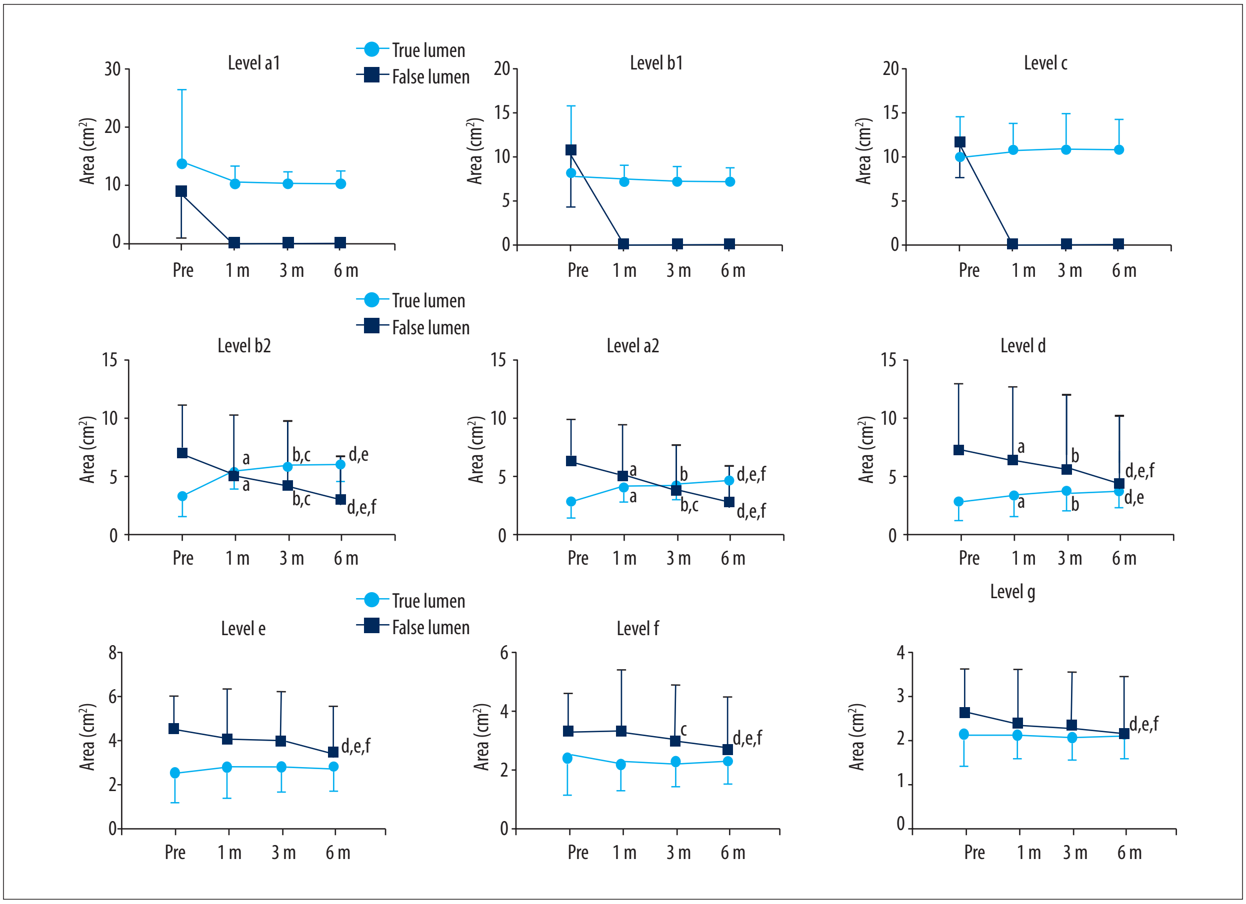

Figure 4. Changes in area of true and false lumen at different levels after Sun's procedure. The levels of a, b, c, d, e, and f were statistically significant (p<0.05). Level a: preoperative *vs.* 1-month; level b: preoperative *vs.* 3-month; level c: 1-month *vs.* 3-month; level d: preoperative *vs.* 6-month; level e: 1-month *vs.* 6-month; level f: 3-month *vs.* 6-month.

to some extent. However, little had been known about aortic remodeling utilized in type A dissection. Therefore, this study demonstrated the evolution of type A aortic dissection after Sun's procedure through observing anatomic changes on follow-up imaging.

The present study indicated that favorable and continuous aortic remodeling was seen in patients who underwent surgical repair for acute type A aortic dissection. But the process differed in degree at different levels. In ascending aorta, because the ascending aorta and arch were reconstructed by artificial vessel, true lumen maintained stable but false lumen vanished. In thoracic descending aorta, true lumen expanded progressively and false lumen regressed gradually over time. In abdominal aorta, the shrinkage or thrombosis of false lumen was slower, which hardly became significant during the three-month period, and the change of true lumen was not significant during follow-up. By resecting diseased ascending aorta and arch, repairing the primary intimal tear, and implanting a stented elephant trunk into the descending aorta, Sun's procedure expanded the true lumen, changed the blood passageway into it, and thus restored the perfusion of organs. In addition, the technique could squeeze the false lumen, reduce the pressure, and promote thrombosis in the proximal descending aorta. Elephant trunk techniques played a pivotal role in reducing the incidence of endoleak, closing distal false lumen, inducing false lumen thrombosis, eliminating secondary tears in the proximal descending aorta, and decreasing future aneurysm formation in downstream descending aorta. It was reported that elephant trunk resulted in false lumen complete thrombosis at the stent graft level in 90–100% of cases followed by false lumen shrinkage [8,13,19]. In the abdominal aorta, the change of hemodynamics was far behind that found in the proximal descending aorta, which suggested that the capacity of aortic remodeling was less in distal aorta. This result was consistent with those reported by Kim et al. [20]; they substantiated the coverage of proximal intimal tear led to lower pressure in residual false lumen, which reduced the risk of aneurysmal expansion and rupture. Nevertheless, our finding was contrast to the results substantiated by Schoder et al. [21], which has proven that the true and false lumen diameter in abdominal aorta level increased in 61% and 56% patients one

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year after surgery, respectively. Therefore, long-term observation provides substantial reinforcement to determine how the abdominal aorta are remodeled.

The prognosis of patients after surgery is closely related to the condition of false lumen thrombosis [22]. Several previous studies have revealed that false lumen patency was related to progressive aortic dilation, while total obliteration of the false lumen might prevent aneurysm formation [10,23–25]. In the patent false lumen, persistent blood flow exerted high sheer stress and circumferential tension on thin incomplete aortic wall causing wall expansion and degradation. On the contrary, in the completely thrombosed false lumen, the flow dynamics was altered to be close to normal resulting in enlargement of true lumen. Sueyoshi et al. found that the growth of the aorta diameter in patients with patent false lumen (4.9 mm/year) was faster than those in patients with partially thrombosis of the false lumen (4.0 mm/year) after surgery, whereas the false lumen diameter decreased in patients with complete thrombosis of the false lumen on the average of 0.2 mm/year [25]. The enlargement of aorta increased the risk of rupture and reoperation, therefore the long-term survival rate was much higher for patients with closed distal false lumen in comparison with patients with open false lumen.

Recently, the prognosis of partially thrombosis was argued frequently. In 70 cases of type A aortic dissection, Rossella et al. found the aortic growth in patients with partial thrombosis was slower than those in patients without thrombus. Moreover, the number of postoperative aortic events in patients with partial thrombosis significantly declined, which concluded that partial thrombosis of false lumen was a protective factor [26]. Similarly, the present study about type A aortic dissection revealed that the regression of false lumen in partially thrombosis was significant compared with the patency of the false lumen. However, in type B aortic dissection Tsai et al. demonstrated three-year survival was lower in patients with partial thrombosis than in patients with patent false lumen [27]. Therefore, more intensive follow-up is required for patients with partial thrombosis.

During follow-up, all patients in this study escaped from a second intervention caused by the dilation of aorta, except one patient who underwent reoperation for persistent aortic root bleeding two months after surgery. Besides, the re-intervention rate was lower than it reported previously [28,29], which may be partly attributed to the short duration of follow-up. Even so, Sun's procedure has been proved as a safe and positive technique for aortic remodeling.

There are several limitations in the present study. First, it was a retrospective review with a relative small number of patients and lacks a control group. The inherent biases are inevitable. Second, the follow-up duration was too short to evaluate aneurismal degeneration. The long-term change of the aorta was unclear, as aortic remodeling may vary over time. Thereby, more than five-year follow-up would be ideal for investigation [30]. In further research, more patients and longer follow-up period are necessary to clarify if the remodeling remains durable for a long time.

Conclusions

Currently, the available evidence has proven that aortic remodeling following Sun's procedure for type A dissection involving the iliac bifurcation is beneficial in the majority of patients. Remodeling happens earlier in the thoracic aorta than in the abdominal aorta after this procedure. Moreover, it is a continuous process and long-term data is required. Complete false lumen thrombosis is favorable for aortic remodeling when compared to patent false lumen.

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Conflict of interest

None declared.

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